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DETERMINATION OF THE INTERNAL TEMPERATURE IN
SATELLITE 1959 ALPHA (VANGUARD II)

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CONTENTS

SUMMARY

Satellite 1959 Alpha was equipped so that accurate measurement of the Minitrack beacon frequency (with the doppler component removed) was sufficient to determine the satellite's internal temperature. To provide a precise measurement of this frequency a sensitive receiving system, utilizing a highly stable but tunable first local oscillator and a noise-eliminating tracking filter, was developed. In addition to the temperature determination, considerable other information such as roll rate and rocket performance was obtained from the observations.

The internal temperature was about 25°C at the time of launch and increased smoothly to approximately 35°C with a thermal time constant of about 36 hours. It advanced only slightly during the next 16 days until March 7, 1959, when it rose very rapidly to about 95°C. After about one day the temperature began to decay exponentially, finally dropping to about 45°C on March 12, 1959. On March 14, 1959 the satellite's battery power supply became exhausted, ending transmission. The abrupt temperature rise to 95°C is attributed to heat released by the satellite telemetry system, which apparently remained on after its last interrogation, draining the remaining power from the batteries.

Other variations in the temperature curve are discussed and what is believed to be the true temperature history of this satellite is presented.

DETERMINATION OF THE INTERNAL TEMPERATURE IN

SATELLITE 1959 ALPHA (VANGUARD II)

INTRODUCTION

The precise frequency of the 108.00-Mc Minitrack transmitter employed in the satellite 1959 Alpha (Vanguard II) is a function of the internal temperature of the orbiting sphere. The relation between the oscillator frequency and the temperature of the quartz crystal controlling it was accurately measured (Figure 1) prior to the launching; thus the internal temperature of the orbiting satellite was determinable from the frequency-temperature curve and precise measurements of the received frequency.

In general, the received signal undergoes a doppler shift resulting from the motion of the satellite with respect to the ground station. In order to determine the actual frequency generated, therefore, it is necessary to read the received frequency at the point where the radial velocity of the satellite with respect to the ground station is zero: for all practical purposes, this is the inflection point of the received frequency plots. A typical doppler frequency curve of 1959 Alpha on one of its early passages, taken at Blossom Point Minitrack Station, is shown in Figure 2. The abrupt discontinuity near the center of the run is the result of a frequency-pulling effect due to interrogation of the 108.03-Mc telemetering transmitter at that point; this effect will be discussed later.

Satellite 1959 Alpha had a radiating pattern which included nulls at particular aspects where the power level was very much less than the maximum power level. Because of the rotation of this satellite, the power received at the ground station alternates between the maximum level and these minimum levels. During the null periods, the receiver output signal is as noisy as it is at extreme ranges, and at times apparently is completely obscured. However, in spite of this poor signal-to-noise ratio at the receiver output, the doppler curves (Figure 2) show a remarkable clarity. This is due to the noise-eliminating characteristics of the tracking filter used in the frequency-detection equipment, which appears in the block diagram of the entire system (Figure 3).

THE FREQUENCY-MEASURING SYSTEM

The 108.00-Mc signals are received by a yagi antenna mounted on an SCR 584 trailer (Figure 4). (The basic SCR 584 parabolic reflector plays no part in the electrical characteristics of the yagi, serving merely as a mechanical support for the guy wires.) A modified Minitrack telemetry receiver amplifies the input signals and translates their frequency to an output frequency of nominally 470 Kc. The local oscillators for the two mixer-converter stages, which have a stability in the order of 3 cps, are adjusted to within 1 cps of the prescribed frequency just prior to a run. A Gertsch FM-6 frequency synthesizer produces the first local oscillator signal, continuously variable in frequency yet highly stable. High stability could, of course, be obtained by means of a crystal-controlled oscillator; however, the tuning feature of the FM-6 is necessary to allow the narrow-band receiver to follow variations in signal frequency.

The second local oscillator is crystal controlled, with a stability of about one part in 10^7. A separate mixer-converter unit converts the 470-Kc second I. F. output signal to a 5-Kc signal. This signal is fed to the input of the tracking filter, which has an operating frequency range from 100 cps to 20 Kc. The local oscillator associated with the third conversion has a stability of better than 1 cps and is actually measured to this precision. To insure the collection of data regardless of possible malfunctions in the tracking, counting, or digitalizing equipment, the input

signal to the tracking filter is recorded on magnetic tape. The electronic equipment within the SCR 584 trailer is shown in Figures 5 and 6.

The tracking filter generates a local approximation of its input signal. This locally generated signal is phase-locked to the input signals by a feedback control loop; thus after a lock has been established, the frequency of the local signal is exactly equal to the incoming frequency. The overall passband of the system is established by a low-pass filter in the feedback loop, whose passband characteristic is variable in five steps from 1 cps to 50 cps. These extremely narrow-bandwidth filters reduce much of the noise superimposed on the input signals, increasing the signal-to-noise ratio markedly. It is the locally generated signal which is conveyed to the counter and digital printer, and it is these data that appear in Figure 2.

To establish a time base for this information, coded impulses from an accurate digital clock are fed to the printer, visual recorder, and tape recorder. To facilitate operations, the d. c. voltage analog of the input frequency is fed to the Sanborn visual recorder to allow a real-time evaluation of the data. In addition, a voltage proportional to the input signal level is recorded along with a voltage which indicates that phase-lock of the tracking filter is being maintained.

Owing to the radiation pattern of the satellite antennas, the received signal level varies with the aspect of the satellite. Since the satellite tumbles in its flight, this variation is cyclical and corresponds with the rotation rate; thus the rotation rate of the satellite can be determined from the signal-level null rate. A daily plot of the rotation rates for this satellite (Figure 7) shows a gradual diminution, which is due principally to magnetic damping of the satellite's rotation by the Earth's magnetic field.

An interesting series of observations was taken with this equipment during the launching of this satellite. The variations in the received frequency during this phase provide much information concerning the performance of the various stages of the launching vehicle (Figure 8). For example, the initiation of the retro-rockets, along with the firing time of the third stage, is clearly evident from changes in the doppler frequency as the satellite velocity changes from these effects. The jitter in the data during second-stage coasting is due to oscillator frequency variations resulting from mechanical vibration. This vibration does not effect the oscillator directly— it can withstand a great deal more stress than this — but rather affects the impedance presented to the oscillator by the antenna as the vibration moves the third stage nose cone with respect to the satellite antennas. The abrupt frequency shifts resulting from the operation of the interrogation system in this satellite (Figures 2 and 8), is also unavoidably caused by variations in the impedance presented to the Minitrack beacon oscillator. The Minitrack oscillator and the telemetry oscillator are both connected to the same antenna system through a bridge network. The impedance at the terminal to which the telemetry oscillator is connected depends upon whether or not the telemetry oscillator is interrogated. This impedance shift is reflected through the bridge only slightly, as indicated by the very slight resulting frequency shift: in the order of two parts per million.

THE SATELLITE TEMPERATURE

The satellite temperature is shown in Figure 7 on a daily basis over the lifetime of the Minitrack transmitter. Each of the points defining this temperature curve is determined by evaluating the frequency at the inflection point of a particular doppler curve similar to that of Figure 2. The first reading, which was taken near the end of the initial orbit, shows a temperature of 25.5°C. In spite of the fact that the closest approach of the satellite to the Blossom Point Minitrack Station was about 2,000 miles during this pass, the extremely weak received signal still provides excellent data for the evaluation of the temperature. The daily readings thereafter show a smooth rise during the following three or four days to a temperature of approximately 34.5°C. During the following ten days the temperature appears to stabilize at this level, after which it tends to rise a few degrees during the following five days. From this point the frequency

data indicate a marked increase in temperature to the height of 95°C. After about one day this temperature began to decay exponentially, levelling off finally at about 50°C. The problem at this stage of the investigation is to determine whether the frequency observations are a true indication of the satellite temperature. It is believed that the evidence that follows substantiates the claim that the temperature data are, in general, correct.

Temperature measurements on the satellite prior to launch indicate that its thermal time constant was about 36 hours. These measurements are substantiated by the shape of the initial rise in temperature shortly after launch and the exponential decay in temperature after the apparent rise to the region of 95°C (Figure 7). Because of this relatively long thermal time constant, the short-time variations in the data can be attributed to errors in determining the inflection points of the doppler curves and to the lack of resolution in translating the frequency to temperature on the curve of Figure 1. The scatter in the data is within one-half degree and is considered negligible in its effect upon the data obtained by the scientific instrumentation.

In general, for constant internal and environmental conditions, the temperature of the satellite would be expected to rise to a particular level and stabilize there. However, there are a number of factors which may not have remained constant. These include the time in sunlight, internal heat generation, variations in the earth's albedo, effects of supply-voltage decay on the generated frequency, and possible variations in the absorptivity/emmissivity ratio. The a/e ratio selected was 1.3*, and the satellite was coated to this specification at the U.S. Army Signal Research and Development Laboratory at Fort Belvoir, Virginia.

The most pronounced deviation from a stabilized condition is obviously the sudden temperature rise to 95°C. The magnitude of the corresponding frequency deviation, 9 Kc, suggests a malfunction of the oscillator. However, other evidence strongly indicates an actual rise in temperature to this height. In crystal-controlled transistor oscillators of this type, a malfunction whereby the frequency is changed this much is extremely unlikely. If the oscillator loses crystal control the tendency is to jump a megacycle or so, or possibly to lock onto a spurious mode of the crystal. However, the nearest spurious mode in this instance is at least 30 Kc away and always on the high side, whereas the frequency shift in question is downward.

A temperature increase of this amplitude requires a significant quantity of heat. Before a successful evaluation can be made, it is necessary to determine the source of this heat. A significant point about the satellite's interrogation system provides a plausible explanation: it is possible that this system did not return to the "off" condition at the end of its final interrogation. The fact that the radiated signal ceased during the last successful interrogation (Woomera 08023837Z, 38 minutes 37 seconds after 2 o'clock GMT on March 8, 1959) before the usual 1-minute period was completed, indicates a strong possibility that the system remained in the "on" position, drawing the remaining current from the batteries and generating the excess heat which drove the temperature to the extraordinary values. Enough information is available to authenticate this hypothesis: if the remaining capacity of the batteries at the termination of the interrogation system operation is assumed to have been 10 percent, the total energy available in the 8 pounds of batteries was 32 watt-hours. The internal package has a specific heat of about 0.2 calories/gram/°C, and a weight of about ten pounds; therefore, about 907 calories are required for a temperature rise of 1°C. Since the total available energy was 27,500 calories, the resultant temperature rise would have been 30°C. The actual satellite temperature rise in question is closer to 50°C; however, various factors including the uneven conduction of heat within the internal package could easily justify this discrepancy. It is interesting to note the result of a mishap which occurred during one of the tests on a satellite of this type. The reset relays after the last of a series of interrogations did not return to the "record" position; this is the same situation that is proposed in answer to the extremely high temperature rise in question. The following morning it was found that the batteries were exhausted and the internal package was

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*A complete report on the thermal design of this satellite by Dr. R. Hanel of USASRDL will be published shortly.

charred from the excessive heat generated. The hypothesis is further substantiated by a re-
duction in the power output of the Minitrack oscillator during the period of high temperature:
this is precisely what is expected of a transistor oscillator operating at these high temperatures.

The temperature curve of Figure 7 exhibits, in addition to the high temperature rise just
discussed, other deviations from the anticipated temperature-stabilized relationship. For ex-
ample, the curve shows a 5-degree temperature rise between the third and the sixth of March.
In addition, the final portion of the curve is somewhat erratic and possesses a rather steep up-
ward slope. However, before attempting to interpret these variations it is necessary to com-
pensate for those variations due to known causes.

The percentage of time the satellite is exposed to sunlight is an important factor in its re-
sultant temperature. For an increase of 1 percent in the time in sunlight, the satellite tempera-
ture is expected to rise 0.7°C. The percentage of time in sunlight for 1959 Alpha is shown in
Figure 9. During the period of temperature measurements the variation amounts to about 4
degrees as can be determined from this curve. The effect of time in sunlight was removed from
the temperature curve of Figure 7 by compensating the data for those times in sunlight deviating
from 73 percent, the value at the time of launch. The method used to compensate these data in-
cluded effects due to the thermal time constant associated with this satellite; that is, each data
point was compensated by an amount proportional to the percentage of time in sunlight that existed
36 hours previous.

Another cause of apparent temperature variation is a decrease in the battery voltage applied
to the transmitter, which results in a change in its frequency. Figure 10 shows this relation and
also the relation between the power output and the supply voltage. In order to determine this
frequency error, the received power from the transmitter was determined several times each day
during the life of the Minitrack transmitter by means of the relation:

$$P_t = \frac{P_r \, (4 \pi R)^2}{G_t \, G_r \, \lambda^2}$$

where P_t is the power transmitted, P_r is the power received, R is the range, G_t is the gain of
the transmitter antenna, G_r is the gain of the receiving antenna and λ is the wavelength at 108.00 Mc
This frequency drop-off causes an apparent rise in temperature, so that the real temperature
when compensated does not have as steep a rise. Although this method provides excellent
measurements of the power radiated in a direction toward the ground station, the wide varia-
tions in the satellite radiating pattern causes the received power to depend upon the satellite's
aspect. As a result the plot of P_t (Figure 11) is rough, but a sufficient number of points were
obtained to adequately define the curve. The temperature curve shown in Figure 12 is the curve
of Figure 7 with variations due to time-in-sunlight and transmitter supply voltage effects removed.

Except for the high temperature rise in the vicinity of March 9, the curve in Figure 12 in-
dicates a rather constant rate of temperature increase from the region of initial stabilization
after launch to the termination of the Minitrack transmission. Various hypotheses have been
advanced for the cause of this gradual increase: (1) erosion or other modifications of the sat-
ellite shell, changing the a/e ratio; (2) changes in the frequency characteristics of the Minitrack
frequency crystal; (3) a very long thermal time constant associated with the internal temperature
characteristics of the satellite; (4) a very slow increase in the earth's albedo during the entire
period. This satellite is coated with a layer of silicon monoxide which is transparent to the
visual spectrum, permitting sunlight to reflect off the polished aluminum surface beneath and
thereby allowing visual observations. This coating serves to regulate the a/e ratio for the infra-
red spectrum in an attempt to provide temperature control within defined limits. If the coating
was modified a temperature change would be expected. Such modification could result from
micrometeor or dust-particle erosion, or from chemical changes due to solar and cosmic radia-
tion. Evidence obtained from previous satellites indicates that collisions with micrometeors or
dust particles to the extent required is highly unlikely; however, chemical reactions might occur
in this material as a result of strong radiations which exist naturally only beyond the earth's
atmosphere.

As an example of the strange occurrences which befall satellites, evidence now tends to indicate that 1959 Alpha was sideswiped by the Vanguard third-stage rocket shortly after separation. Several facts support this idea, among them the fact that the third-stage orbital velocity is greater than that of the satellite as determined by optical observations. Ideally, third-stage burning should cease before separation of the satellite; however, it is now felt that in this case residual gases and slivers of burning propellant remained to accelerate the third stage after separation. The normal separation velocity is about 3 feet/second, and results from the release of a spring mechanism. The excess velocity of the third stage has been roughly computed as 200 feet/second. In spite of the rather high relative velocities of the two bodies the satellite was apparently not damaged; however, its tumbling, as determined by the variations in received signal level, could be the result of such a mishap. Another significant possibility is that carbonized gases issuing from the rear of the third stage could have partially coated the satellite as it was overtaken. The resulting change in the a/e ratio would account for the slightly higher temperatures encountered in the satellite as compared to the 30°C design center.

The temperature curve of Figure 12 also shows a small variation about February 24 and another around March 4 to March 7. This type of variation is very likely due to variations in the earth's albedo, which is capable of causing a maximum variation of 5°C.

CONCLUSIONS

It is believed that the temperature curve shown in Figure 7, using the dashed portion during the final period, is the true temperature history of 1959 Alpha. It was first suggested that the data after about March 2 were invalid owing to a malfunction in the Minitrack transmitter. However, further evidence indicates that, except for an error in the final period due to transmitter voltage decay, the actual temperature was probably as indicated. It is hoped that this evaluation of the temperature data obtained on this satellite will aid the scientific experimenters in their evaluation of the data obtained from the scientific instrumentation enclosed within the sphere.

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6

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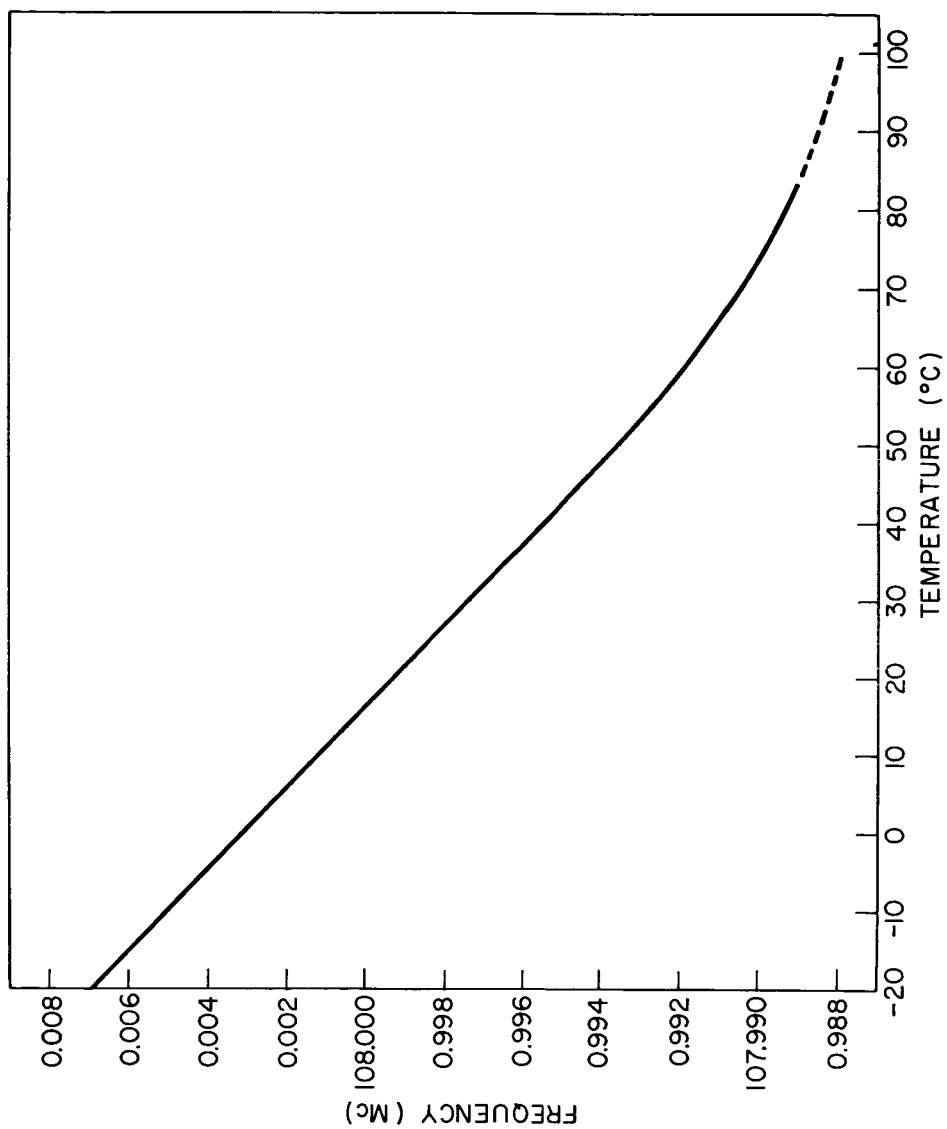
Fig. 1 – Frequency as a function of temperature of the 1959–Alpha
Minitrack transmitter
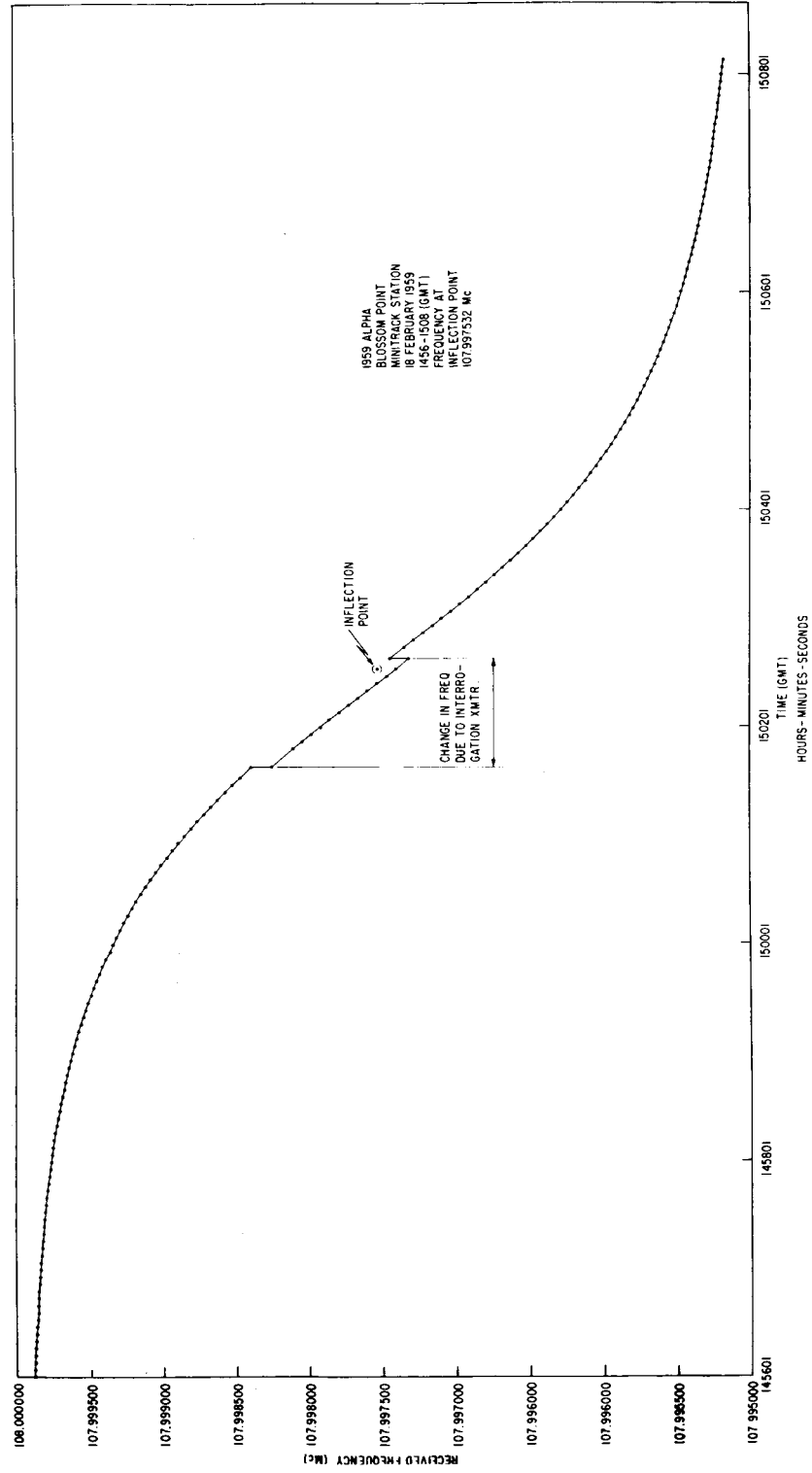
Fig. 2 – Typical received frequency curve of 1959–Alpha during a passage at the Blossom Point Minitrack Station
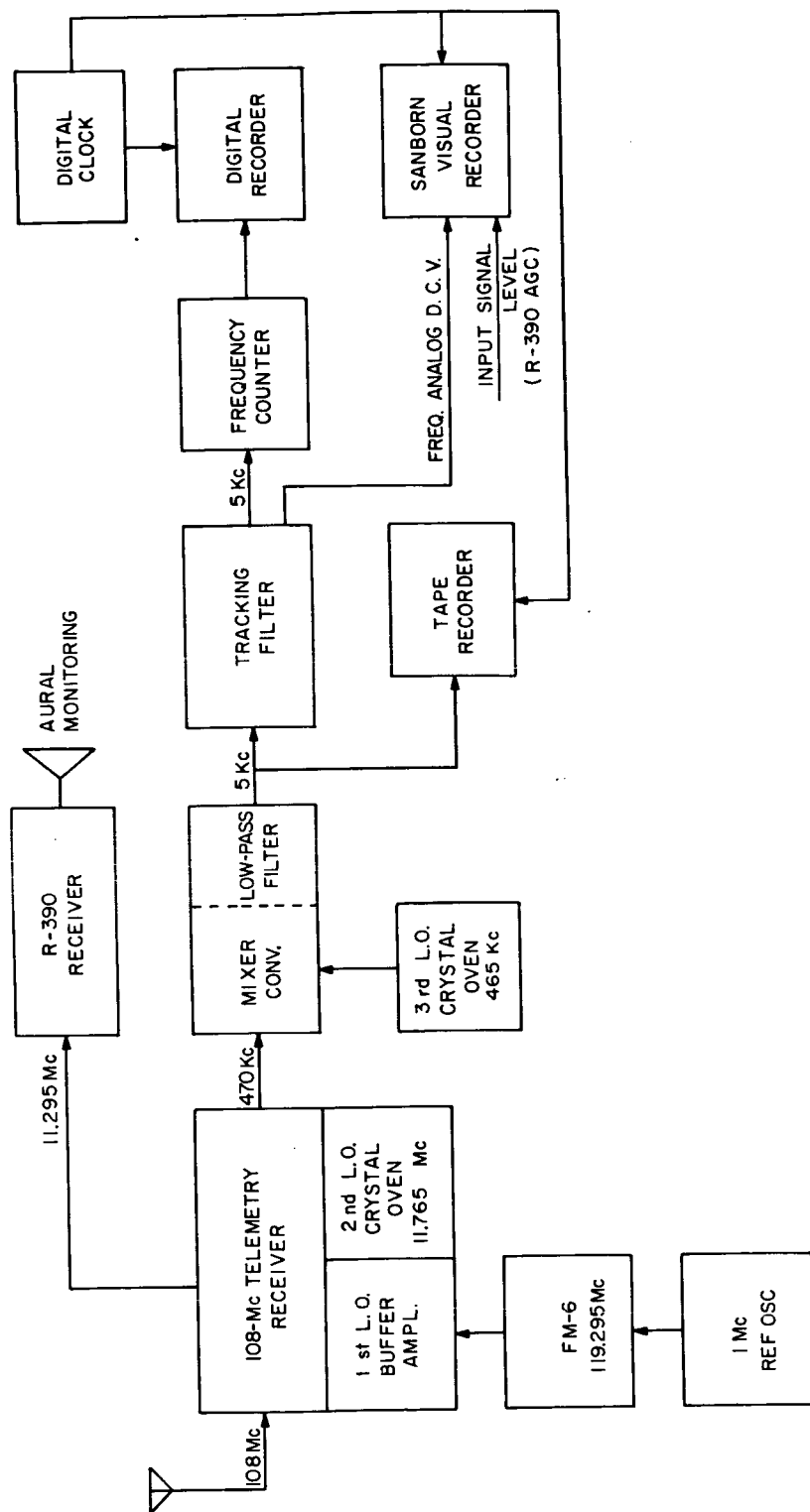
Fig. 3 – Frequency-detection system used at the Blossom Point Minitrack Station

Fig. 4 - SCR-584 trailer with antenna
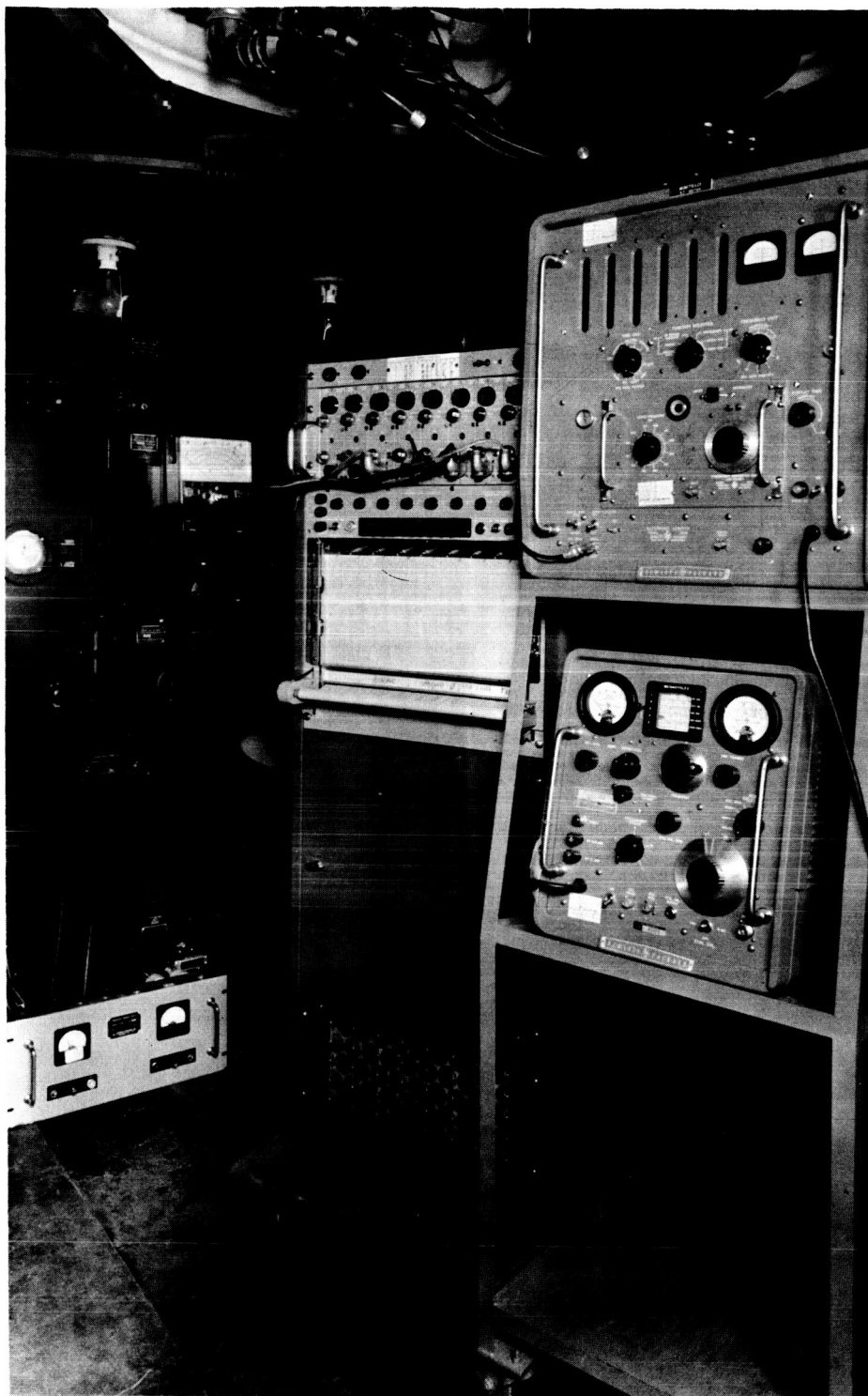
Fig. 5 - Interior of SCR-584 trailer
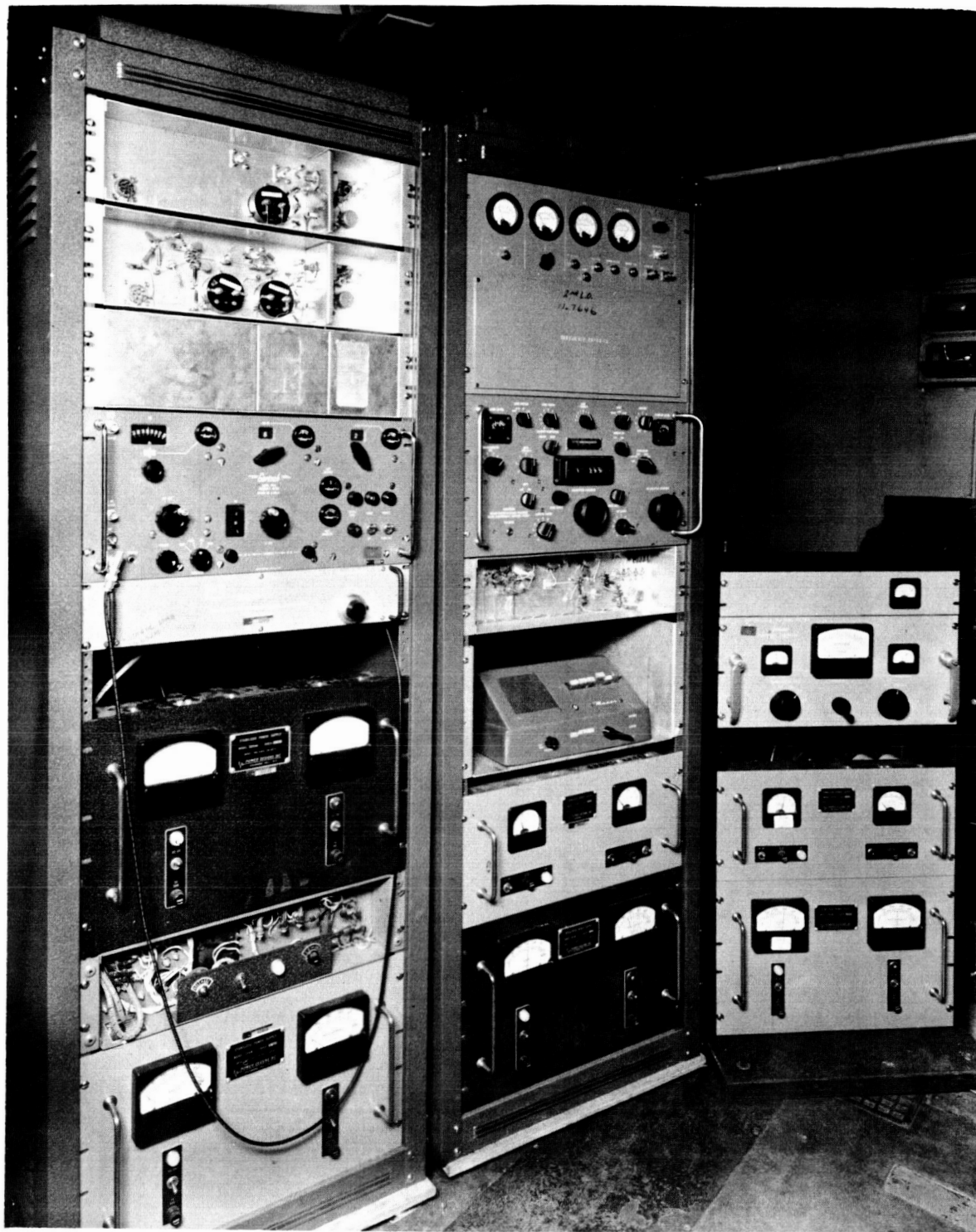
Fig. 6 - Interior of SCR-584 trailer

13
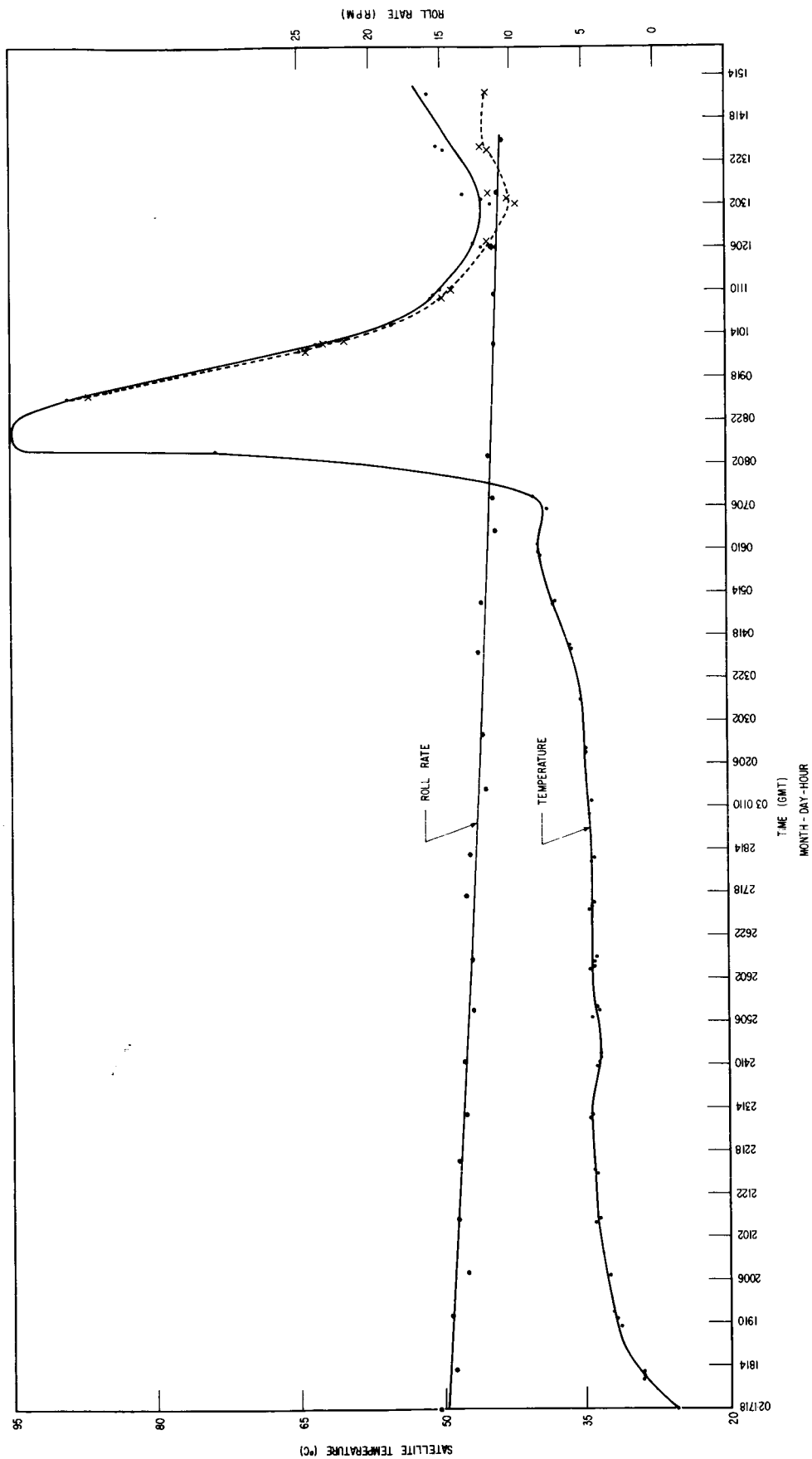
Fig. 7 – Temperatures and roll rates of Satellite 1959-Alpha taken at Blossom Point, February 17 – March 15, 1959
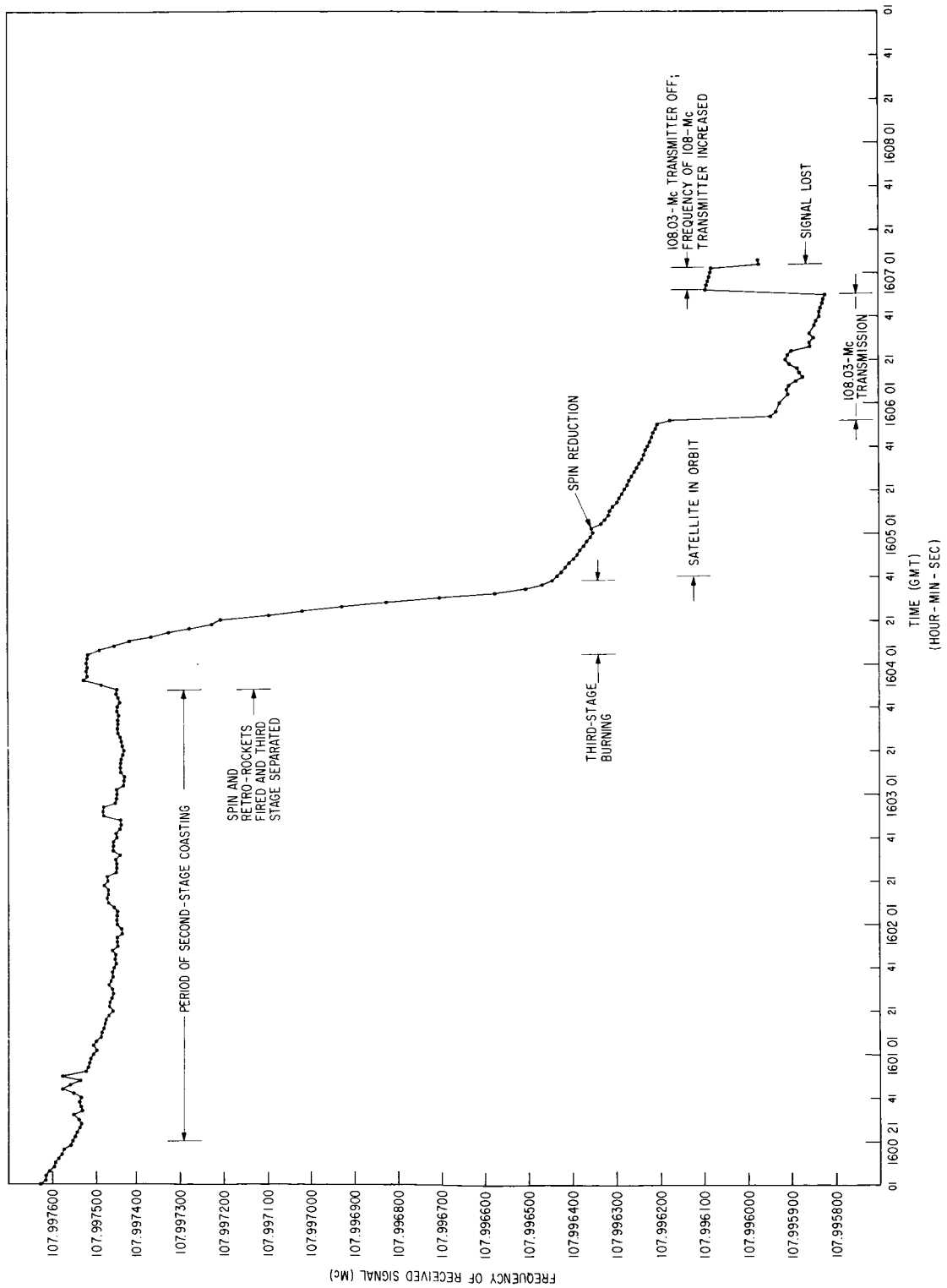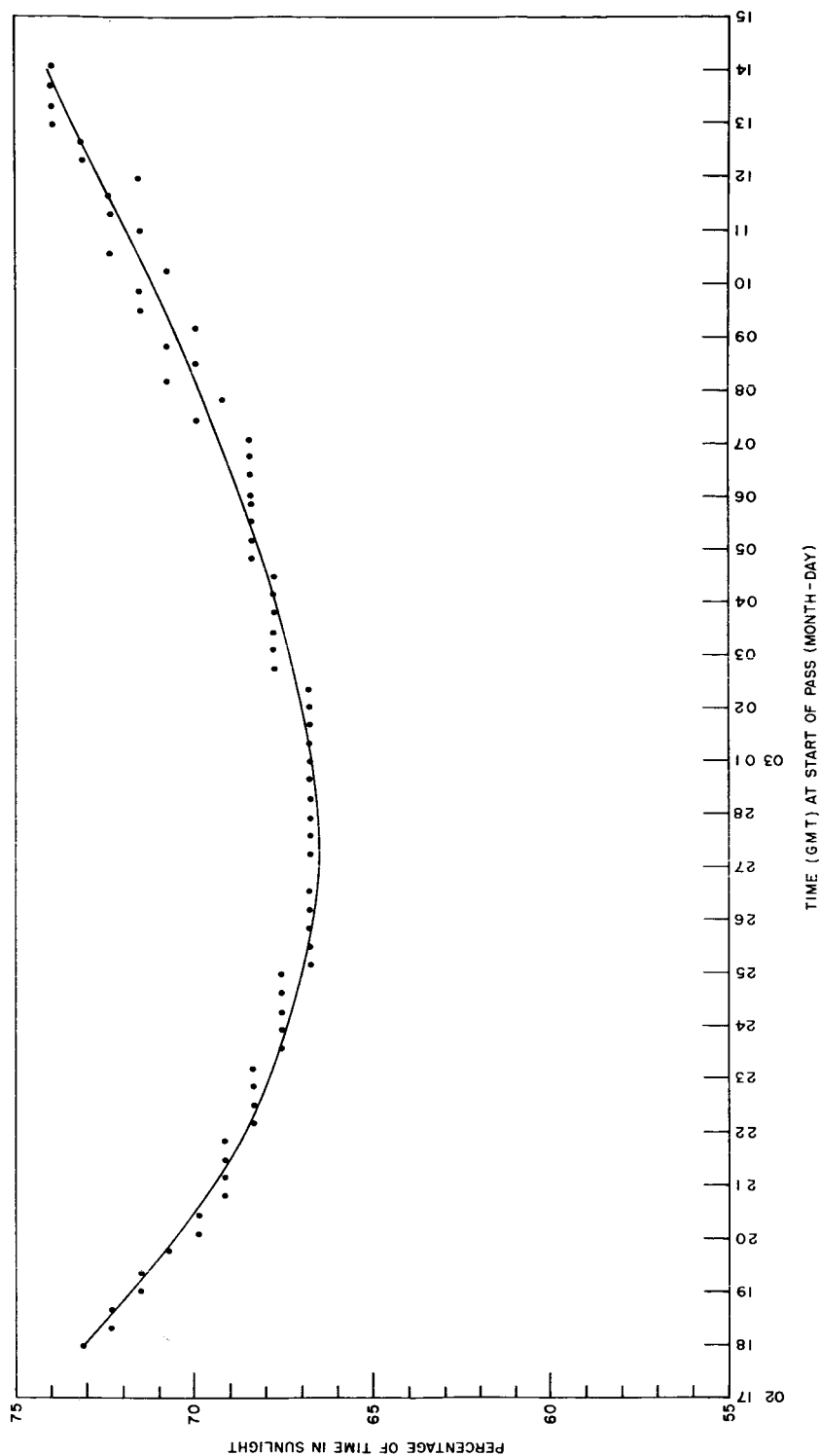
Fig. 8 – Received signal frequencies of 1959-Alpha during launch

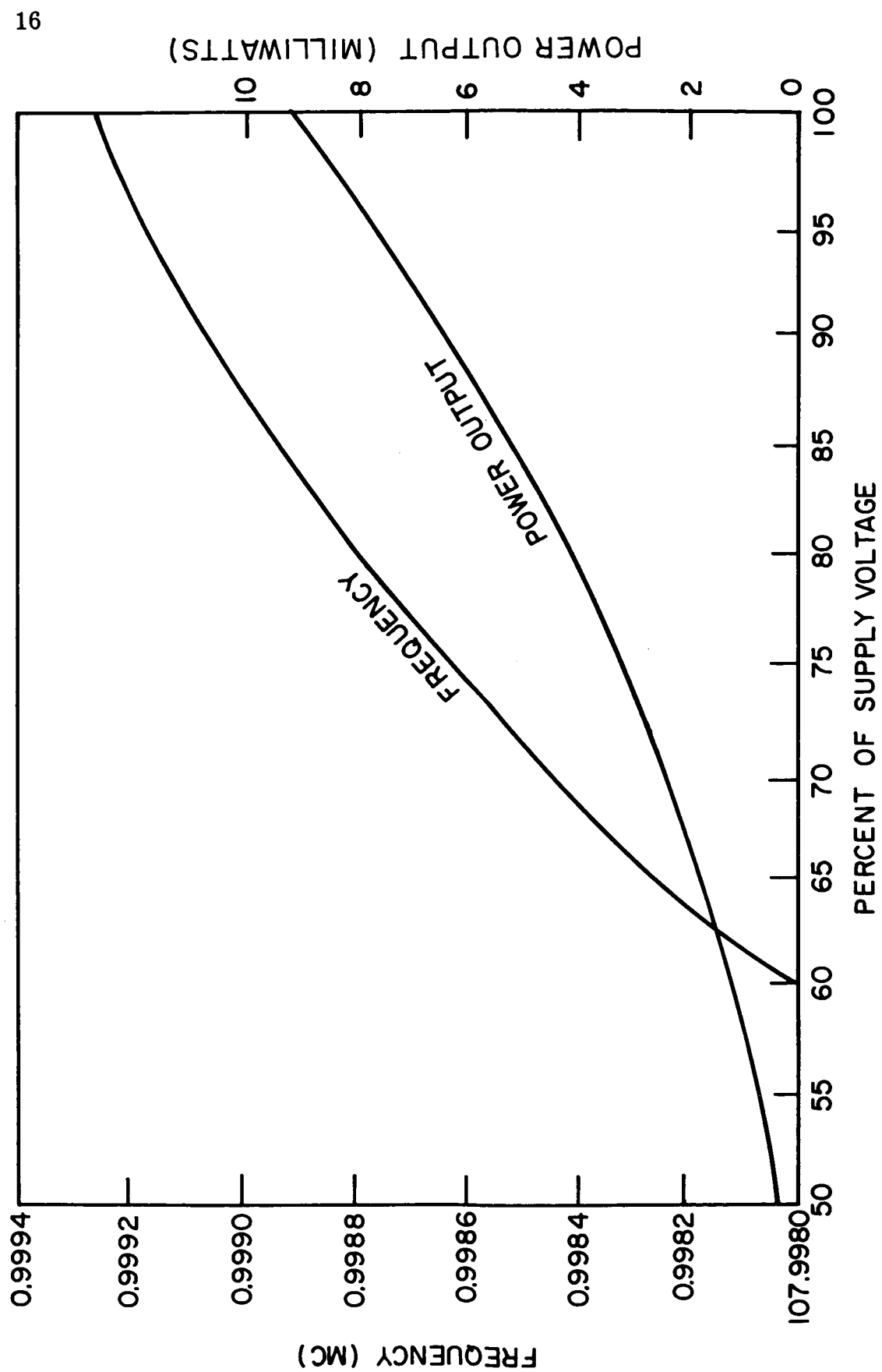Fig. 9 – Percentage of time in sunlight for 1959–Alpha, February 17 – March 15, 1959

Fig. 10 – Frequency and power output of Minitrack transmitter as a function of supply voltage
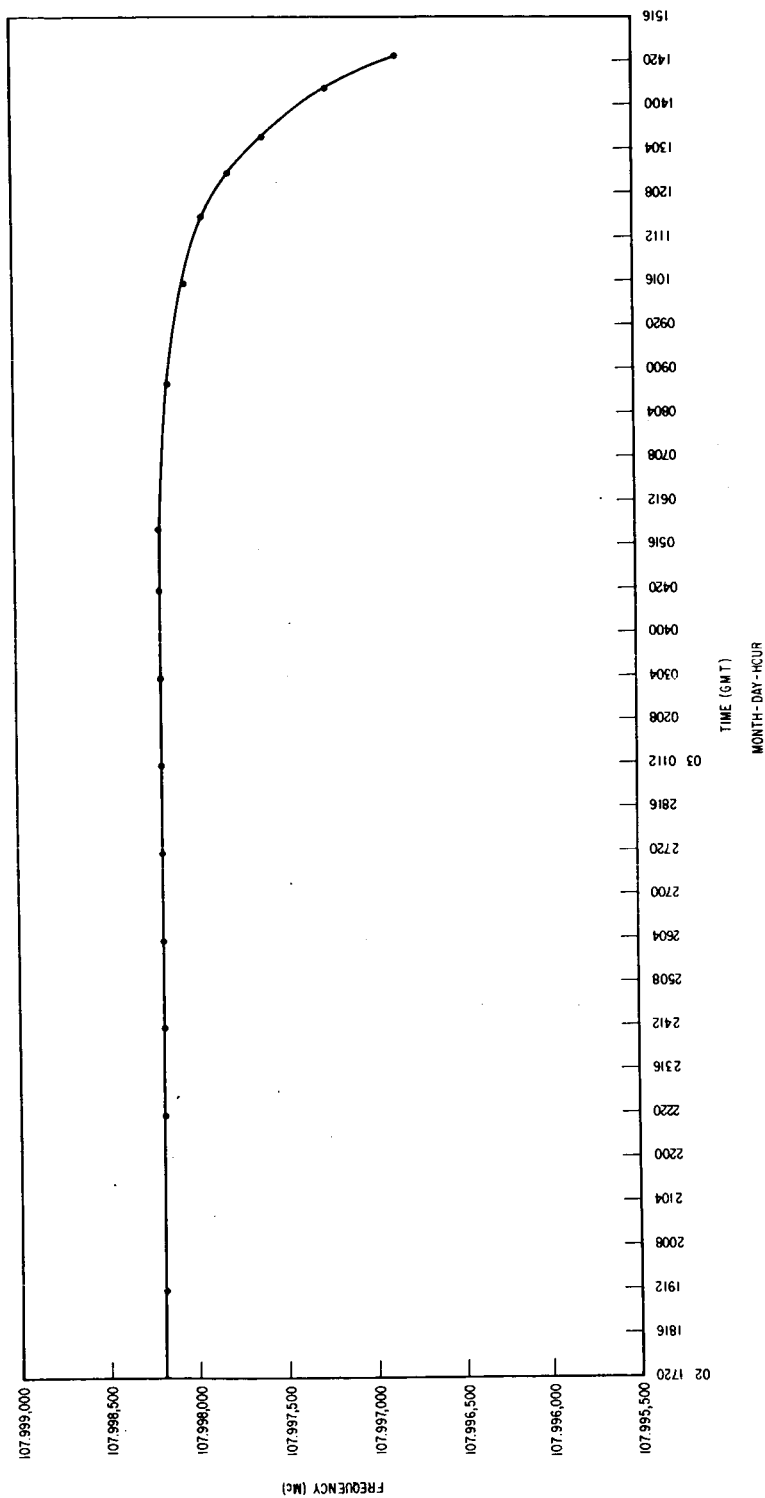
Fig. 11 – Frequency variation of 1959-Alpha Minitrack transmitter due to decreasing supply voltage, February 17 – March 15, 1959
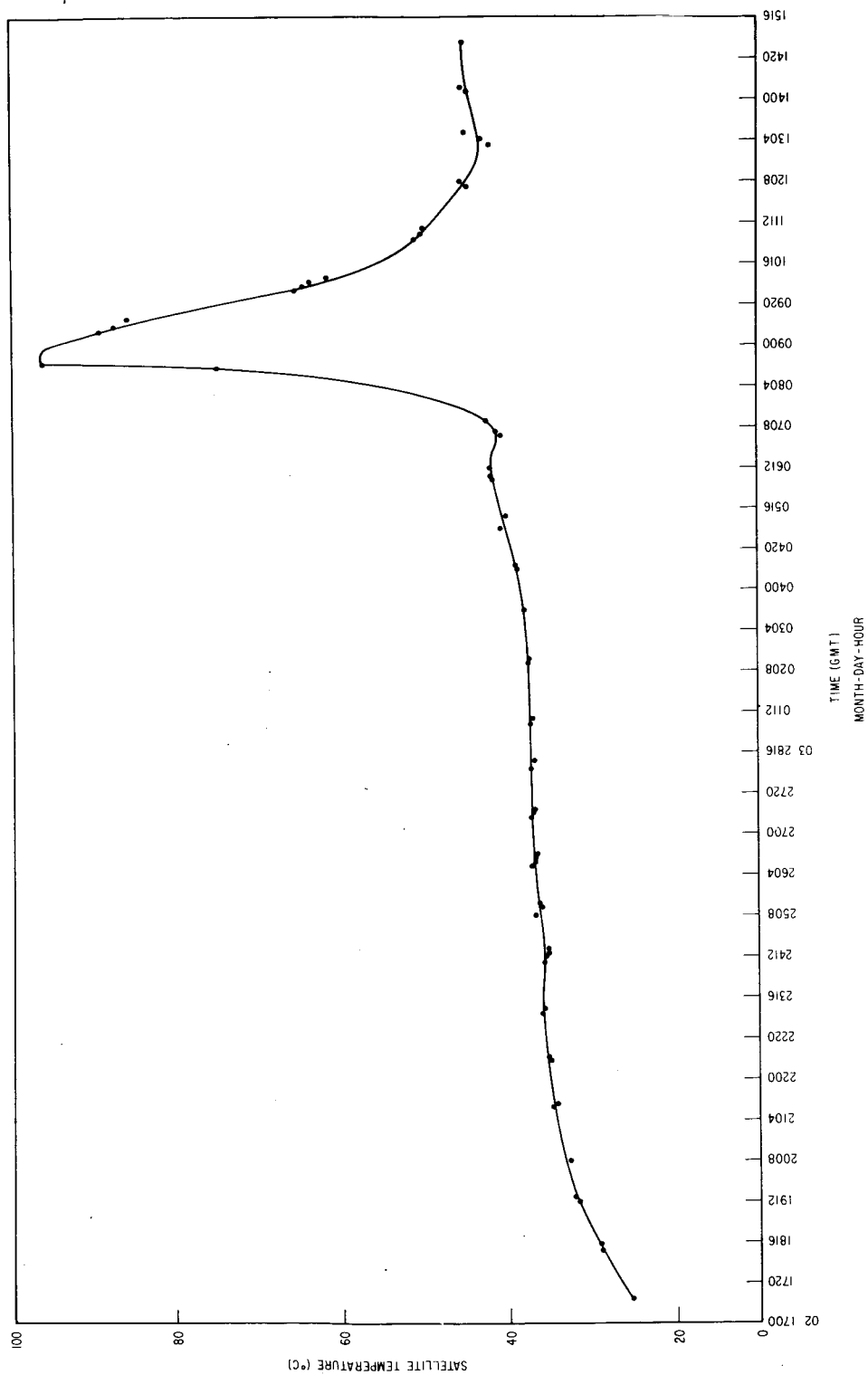
Fig. 12 – Temperatures of 1959-Alpha with effects of sunlight-time and supply-voltage variations removed